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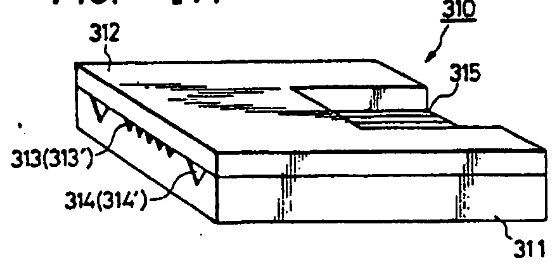
(54) Process for producing an optical connector.

(57) A process for producing an optical connector comprises the steps of: preparing a substrate plate wafer and a cover plate wafer; forming a plurality of optical fiber grooves on a top surface of said substrate plate wafer and a plurality of windows in said cover plate wafer; stacking the cover plate wafer on the substrate plate wafer; heating the cover and substrate plate wafers at an elevated temperature to join them into a unitary assembly; cutting the unitary assembly in a direction that is parallel to the plurality of optical fiber grooves and in a direction that is perpendicular to the plurality of optical fiber grooves and in traversing the centers of the plurality of windows in the cover plate wafer to produce a plurality of chips of optical fiber connector ferrule having a cutout in the rear portion of each cover plate; and fixing a plurality of optical fibers in a fiber array in position in a plurality of optical fiber holes.

FIG. 1A



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PROCESS FOR PRODUCING AN OPTICAL CONNECTOR

FIELD OF THE INVENTION

The present invention relates to a process for producing an optical connector used in coupling optical connector ferrules together for fixing optical fibers in position in lightwave communications systems.

SUMMARY OF THE INVENTION

An object of the invention is to provide a process which allows large-scale production of optical fiber coupling members.

A further object of the present invention is to produce simultaneously a plurality of optical fiber coupling members without impairing the dimensional precision of the couplers.

A still further object of the present invention is to produce optical fiber coupling members that allow easy insertion of the optical fibers and are capable of positioning optical fibers with dimensional precision.

The aforementioned object of the present invention can be achieved by providing a process for processing an optical fiber connector which comprises the steps of: preparing a substrate plate wafer and a cover plate wafer; forming a plurality of optical fiber grooves on a top surface of the substrate plate wafer and a plurality of windows in the cover plate wafer; stacking the cover plate wafer on the substrate plate wafer; heating the cover and substrate plate wafers at an elevated temperature to join into a unitary assembly; cutting the unitary assembly in a direction that is parallel to the plurality of optical fibered grooves and in a direction that is perpendicular to the plurality of optical fiber grooves and in traversing the centers of the plurality of windows in the cover plate wafer to produce a plurality of chips of optical fiber connector ferrule having a cutout in part of the rear portion of each cover plate; and fixing a plurality of optical fibers in the fiber array in position in a plurality of optical fiber holes.

By carrying out the process of the present invention a plurality of optical fiber coupling members can be produced simultaneously without impairing the dimensional precision of the couplers. Furthermore, because of their removal of the portion of the cover plate which lies over the rear part of the optical fiber guide grooves, optical fibers can easily be inserted into the optical fiber guide holes.

According to a special embodiment of the present invention, each of the optical fiber connector ferrules is surrounded with a plastic housing except in the area corresponding to the cutout in the rear part of the cover plate.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A is a perspective view of an optical fiber coupling member according to the present invention;

Fig. 1B is a cross section of an optical fiber coupling member shown in Fig. 1A;

Fig. 1C is a top view of the optical fiber coupling member shown in Fig. 1A;

Fig. 1D is a side view of the optical fiber coupling member shown in Fig. 1A.

Figs. 2A to 2C show the sequence of procedures for fabricating an optical connector using the optical fiber coupling member shown in Figs. 1A and 1B;

Figs. 3A to 3F show the sequence of procedures for producing the optical fiber coupling member of the present invention;

Figs. 4A to 4C illustrate a technique for establishing direct silicon-to-silicon bonding; and

Fig. 5 is a perspective view showing a mechanical splicer according to the present invention;

Fig. 6 is a perspective view showing an optical fiber coupling member of the present invention;

Figs. 7A and 7B show an optical fiber coupling member accommodated in a plastic housing;

Fig. 8 is a top view of two units of the optical fiber coupling member in the plastic housing; and

Fig. 9 illustrates how the optical fiber coupling member of the present invention presents an adhesive agent from flowing out of the member.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figs. 1A to 1D illustrate an optical fiber coupling member manufactured in accordance with the process of the present invention.

As shown in Figs. 1A and 1B, a cover plate 312 placed on top of a grooved substrate 311 that has optical fiber guide grooves 313 and guide pin grooves 314 formed in its top surface is heated at an elevated temperature without employing any adhesive agent so as to produce a unitary assembly which has optical fiber guide holes $313'$ and guide pin holds $314'$ formed in its interior. A cutout 315 is formed in the rear portion of the cover plate 312 in such a way that part of the optical fiber guide grooves 313 becomes exposed to facilitate subsequent insertion of optical fibers.

The grooved substrate 311 is joined to the cover plate 312 in the following manner. The surfaces of the two members at which they are to be joined together are ground and polished to high dimensional precision and direct bond is temporarily established by wringing: the combination is then heated to an elevated temperature, say 1,000°C or more so that any impurities, water and other unwanted matter present at the interface between the two members are evaporated to activate their surfaces to such an extent that they are directly bonded together into a unitary assembly. As will be described later in this specification, two large plate units, say, wafers may be employed, one wafer being a grooved wafer that has a plurality of optical fiber guide grooves and guide pin grooves formed by machining, and the other being a cover plate wafer. If these two wafers are bonded by the method described above and are subsequently cut into discrete chips, a number of coupling members in a chip form can be produced simultaneously.

Since optical fiber guide holes 313′ are already present in the optical fiber coupling member 310 of the present invention, an optical connector or a mechanical splicer can be produced by simply inserting and fixing optical fibers in these guide holes without requiring any difficult assembly operations as in the prior art.

Figs. 2A to 2C show the sequence of procedures for fabricating an optical connector using the optical fiber coupling member shown in Figs. 1A and 1B. First, as shown in Fig. 2A, the optical fibers (B) in a fiber array (A) are inserted into optical fiber guide holes 313′ from the cutout 315 in the rear portion of the cover plate 312 of the coupling member 310; then, as shown in Fig. 2B, the optical fibers (B) are fixed in the guide holes 313′ with an adhesive agent 316; thereafter, as shown in Fig. 2C, the coupling member 310 is accommodated in a housing 317 and two units of such coupling member are positioned in a face-to-face relationship, with guide pins (C) being inserted into the guide pin holes 314′ in each coupling member in such a way that the two coupling members are coupled together. The coupled members are finally secured with a clamper (D).

The process for producing an optical connector such as shown in Figs. 1A to 1D will now be described.

Figs. 3A to 3F show the sequence of procedures for producing the optical fiber coupling member of the present invention on a commercial scale.

First, a cover plate wafer 332 that may be made of silicon and which, as shown in Fig. 3A has a plurality of rectangular windows 334 is provided. Also, a grooved silicon wafer 331 which, as shown in Fig. 3B has a plurality of optical fiber guide grooves 333 formed by machining is provided. The surfaces of the two wafers at which they are to be joined together are ground and polished to high dimensional precision and are temporarily bonded by wringing. Thereafter, the combination is heated to a temperature of, say 1,000°C and upward to activate the mating surfaces in such a way that the two wafers are strongly bonded together into a unitary assembly without using any adhesive agent (see Fig. 3C).

For the theory of direct silicon-to-silicon bonding, see, for example Denki Joho Tsushin Gakkaishi (in Japanese), vol. 70, No. 6, p. 593-595, June 1987, which states as follows: "The surface of a silicon oxide film has OH groups that have been formed as a result of reaction with water. The surface of silicon is in the same state since it has a spontaneously formed oxide film present. If these OH groups are activated and brought into direct contact, hydrogen bonds wi 11 be formed (Fig. 4A). Upon further heating, the OH groups will undergo dehydrative condensation to produce Si-O-Si bonds (Fig. 4B). If the oxide film present in silicon-to-silicon bonding is extremely thin, oxygen will diffuse into the bulk of silicon, thereby forming Si-Si bonds (Fig. 4C).

As discussed above, silicon in its usual state has impurities and water adsorbed on its surface and silicon-to-silicon bonding is inhibited by such adsorbates. If silicon is heated to an elevated temperature of, say, 1,000°C and upward, the adsorbates are evaporated to provide an activated silicon surface. However, this process will not work effectively for a large surface area to be bonded because it generally does not have any passage for evaporation of the adsorbates. But in the present invention, the grooved wafer has a number of optical fiber guide grooves formed in its surface and it may be provided with additional grooves that run across it for the specific purpose of providing channels for evaporation. In addition, the cover plate wafer is provided with a plurality of rectangular windows. These grooves and windows will combine together to contribute to efficient bonding of the two wafers.

In the manner described above, the grooved wafer 331 and the cover plate wafer 332 are joined into a unitary assembly 335. Then, as shown in Fig. 3D, the assembly is cut both in a direction 337 that is perpendicular to the optical fiber guide grooves 333 and in a direction 336 parallel to said grooves, thereby producing a number of optical fiber coupling members 310 in a chip form as shown in Fig. 3E. In this case, cutting in the direction 337 which is perpendicular to the optical fiber guide grooves 333 results in traversing the centers of the windows 334 in the cover plate wafer 332, so this cutting operation will simultaneously produce a cutout 315 in the rear portion of each cover plate 312.

After obtaining the discrete chips of optical fiber coupling member 310, the optical fibers in a fiber array (A) are fixed in position in the optical fiber guide holes 313′. The individual chips are then accommodated in a housing 317 to make optical connectors as shown in Fig. 3F.

Example:

Two silicon wafers were ground and polished to provide a specular surface. One of these wafers was provided with a continuous pattern of V-shaped optical fiber guide grooves and guide pin grooves. These guide grooves were made with the same cutting wheel except that the depth of the optical fiber guide grooves was different from that of the guide pin grooves. Cutting is just one example of the method of machining silicon wafers and the same result can be attained by either etching or molding. The shape of the grooves to be formed is not limited to the V-shape, either. Both the optical fiber guide grooves and the guide pin grooves were V-shaped with an angle of about 60° and precision-machined to an accuracy of 0.1 µm so that they would accommodate inscribed circles having diameters of 0.125 mm and 0.500 mm, respectively. The optical fiber guide grooves had a pitch of 0.25 mm and were six in number, whereas the two guide pin grooves had a pitch of 5 mm. This wafer and the other wafer were thoroughly cleaned on the surfaces at which they were to be joined together. The two wafers were then bonded temporarily by wringing and subjected to a heat treatment at about 1,000°C. During the heat treatment, the two wafers were pressed with a ceramic clamp to ensure that they would be intimately bonded together. As a result, the two wafers were successfully bonded to each other over substantially the whole area, and the resulting assembly was cut to produce a plurality of discrete chips of optical fiber coupling member having a desired size.

Each of the optical fiber coupling members in a chip form was equipped with optical fibers and accommodated in a housing to make a six-fiber optical connector. Guide pins having an outside diameter of 0.499 mm were inserted into the guide pin holes in any two of the fabricated optical connectors in such a way that they were coupled together. Measurement of coupling loss of these connectors on single-mode fibers gave a value of 0.21 dB as an average for 120 fibers (n = 120). In addition to their loss-property, the connectors were very simple to assemble.

In order to evaluate the reliability of the connectors at the bonded surface, they were subjected to a variety of tests including a heat cycle test (−40°C to +70°C), a wet heat resistance test (80°C x 95% rh), an impact test and a failure test. In none of the tests conducted did the couplers develop any phenomenon that would be a problem in practical applications.

The foregoing explanation of the Example was directed to an optical connector. However, it should be noted that the optical fiber coupling member of the present invention can be applied to a mechanical splicer of the type shown in Fig. 5 in which optical fiber guide grooves 313 become exposed on both sides when a cover plate 312 is joined to the top surface of a grooved substrate 311 and in which optical fibers are inserted into these guide grooves in such a way that they abutt against each other in optical fiber guide holes. Fig. 6 shows another modification of the optical fiber coupling member of the present invention; when a grooved substrate 311 and a cover plate 312 are joined in such a way that their end surfaces are in the same plane, part of the optical fiber guide grooves 313 becomes exposed, with a step portion 318 for fixing an array of optical fibers being provided in the rear end portion of the grooved substrate 311.

As described in the foregoing, the optical fiber coupling member of the present invention differs from the prior art in that it does not employ a sandwich structure in which a cover plate is bonded to a grooved substrate with a layer of an adhesive agent being interposed therebetween. Instead, the optical fiber guide holes in the coupling member of the present invention are formed by directly bonding a cover plate to a grooved substrate through heat treatment without using any adhesive agent. The coupling member of the present invention can be easily assembled by merely inserting optical fibers into these optical fiber guide holes. The optical fiber coupling member of the present invention exhibits strong adhesion between the cover plate and the grooved substrate, can be machined to high dimensional precision, and ensures high reliability.

According to the process of the present invention, two wafers, one being a substrate wafer provided with guide grooves by machining and the other being a cover plate wafer, are joined and the combination is cut into discrete chips of coupling member in which a grooved substrate and a cover plate are joined into a unitary assembly. Therefore, the process of the present invention is adapted for large-scale production of optical fiber coupling members. In joining two wafers by heat treatment, any water and impurity present on the surface of each wafer must be removed and this can be achieved efficiently by making use of guide grooves and other grooves that run across the combination of two wafers.

As shown in Figs. 1A and 1D, a cover plate

312 which is typically made of silicon is joined to a grooved substrate 311 that may also be made of silicon and which has optical fiber guide grooves 313 and guide pin grooves 314 formed in its top surface by machining so as to provide an assembly having optical fiber guide holes 313′ and guide pin holes 314′ formed in its interior. The portion of the cover plate 312 which lies over the rear part of the optical fiber guide grooves 311 is removed to form a cutout 315 so that optical fibers can be easily inserted into the optical fiber guide holes 313′. On the other hand, the portion of the cover plate 312 which lies over the guide pin grooves 314 is not removed so that an adhesive agent 318 which is injected in order to securely fix optical fibers in the optical fiber guide holes 313′ and grooves 313 will not flow into the guide pin grooves (see Fig. 9).

In the optical fiber coupling member of the present invention, optical fiber guide holes are formed by simply joining a grooved substrate and a cover plate. Therefore, optical fibers can be easily inserted and assembled to provide a coupling member that is capable of positioning optical fibers with dimensional precision.

The optical fiber coupling member of the present invention can be produced by performing precision-bonding of a cover plate to a grooved substrate that has been provided with guide grooves by precision machining. Therefore, by employing wafers as the starting grooved substrate and cover plate, a plurality of optical fiber coupling members can be produced simultaneously without impairing the dimensional precision of the couplers.

The optical fiber coupling member of the present invention is also characterised in that a cutout is provided by removing the portion of the cover plate which lies over the rear part of the optical fiber guide grooves and this allows optical fibers to be easily inserted into the optical fiber guide holes. If, in this case, the portion of the cover plate which lies over the guide pin grooves is left intact (i.e., remains bonded to the grooved substrate), it can be ensured that an adhesive agent used in order to fix optical fibers will not flow out of the system or flow into the guide pin grooves.

Example:

As shown in Fig. 3A, a silicon wafer 332 serving as a cover plate was provided with a plurality of rectangular windows 334 by a suitable method such as etching. As shown in Fig. 3B, another silicon wafer 331 that would serve as a grooved substrate was provided with a continuous pattern 333 of optical fiber guide grooves and guide pin grooves by cutting with a V-shaped diamond wheel. Both guide pin grooves and the optical fiber guide grooves were precision-machined so that they would accommodate inscribed circles having diameters of 0.5 mm and 0.125 mm, respectively. The rectangular windows 334 may be formed by ultrasonic working instead of etching, and the V grooves may be produced by etching utilizing the anisotropic nature of silicon.

The two wafers 332 and 331 were then joined precisely to produce an assembly 335 as shown in Fig. 3C. Precision joining may be achieved either by using a thin film of adhesive agent or by direct silicon-to-silicon bonding involving a heat treatment at elevated temperatures. The resulting assembly was cut into a predeterimined shape along lines 336 and 337 as shown in Fig. 3D, thereby producing discrete chips of optical fiber coupling member 310 each having a cutout 315 in the cover plate 312 lying over the rear part of the optical fiber guide grooves 313 (see Fig. 3E).

Each of the optical fiber coupling members 310 in a chip form was accommodated in a plastic housing 316 as shown in Figs. 7A and 7B.

Figs. 7A and 7B show an optical fiber coupling member accommodated in a plastic housing; Fig. 7A is a perspective view, and Fig. 7B is a longitudinal section showing an optical fiber (B) fixed in position in the optical fiber coupling member 310. As shown, the plastic housing 316 has a step portion 318 in which an array of optical fibers (A) is to be fixed by adhesive bonding. In the embodiment shown in Fig. 7A, the plastic housing 316 is also provided with a cutout 317 in its top surface in an area that corresponds to the cutout 315 in the cover plate 312 of the optical fiber coupling member 310. This cutout 317 facilitates the insertion of optical fibers (B) into the optical fiber guide holes 313′. As is also shown in Figs. 7A and 7B, the optical fiber coupling member 310 projects by a distance of about 0.5 mm from the front face of the plastic housing 316 in which it is accommodated. This offers the advantage that the coupling member which requires to be ground and polished is limited to the front face of the optical fiber coupling member 310.

Fig. 8 is a top view of two units of the optical fiber coupling member 310 in the plastic housing 316 that are coupled together by means of guide pins and which have been secured in position with a clamper 319. In order to evaluate the performance of the optical fiber coupling member of the present invention, six-fiber optical connectors on single-mode fibers were fabricated and subjected to a test; they achieved a very low average coupling loss of about 0.23 dB with an index-matching medium.

The foregoing explanation of the Example was directed to an optical connector. However, it should be noted that the optical fiber coupling member of

the present invention can of course be applied to a mechanical splicer in which optical fibers are coupled in alignment by being allowed to abutt against each other in the same guide groove. In this case, too, a cutout may be provided in part of the cover plate in order to prevent an adhesive agent from flowing out of optical fiber guide grooves to affect other sites of the splicer.

As described on the foregoing pages, the optical fiber coupling member of the present invention allows for easy insertion of optical fibers into optical fiber guide holes, thereby improving the efficiency of assembly operations.

In the optical fiber coupling member of the present invention, a cutout is made in the portion of the cover plate which lies over the rear part of the optical fiber guide grooves while the portion of the cover plate lying over the guide pin grooves is left intact and remains bonded to the grooved substrate. This arrangement is effective in preventing an adhesive agent injected into the optical fiber guide grooves from flowing into the guide pin grooves or from flowing out of the system.

In addition, the optical fiber coupling member of the present invention can be fabricated in a high production rate by employing wafers as the starting grooved substrate and cover plate.

Claims

1. A process for producing an optical connector, comprising the steps of:
preparing a substrate plate wafer and a cover plate wafer;
forming a plurality of optical fiber grooves on a top surface of said substrate plate wafer and a plurality of windows in said cover plate wafer;
stacking said cover plate wafer on said substrate plate wafer;
heating said cover and substrate plate wafers at an elevated temperature to join them into a unitary assembly;
cutting said unitary assembly in a direction that is parallel to said plurality of optical fiber grooves and in a direction that is perpendicular to said plurality of optical fiber grooves and in traversing the centres of said plurality of windows in said cover plate wafer to produce a plurality of chips of optical fiber connector ferrule having a cutout in part of the rear portion of each cover plate; and
fixing a plurality of optical fibers in a fiber array in position in a plurality of optical fiber holes.

2. A process for producing an optical connector as claimed in claim 1, further comprising the step of surrounding each of said plurality of chips of optical fiber connector ferrule with a plastic housing except in the area corresponding to said cutout in said cover plate.

FIG. 1A

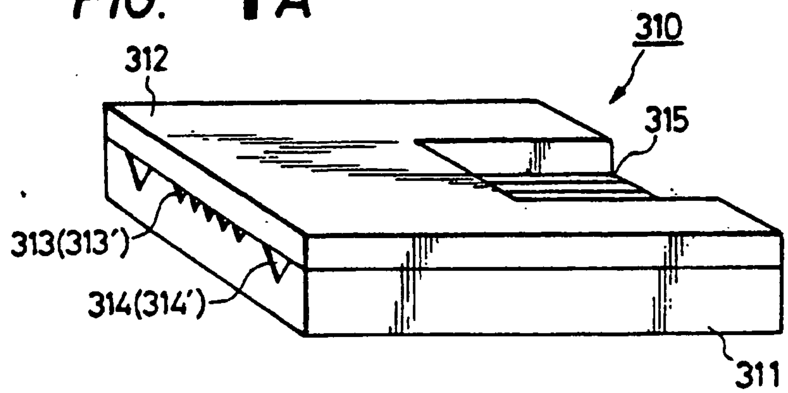

FIG. 1B

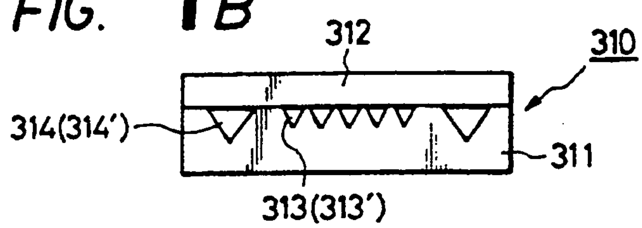

FIG. 1C

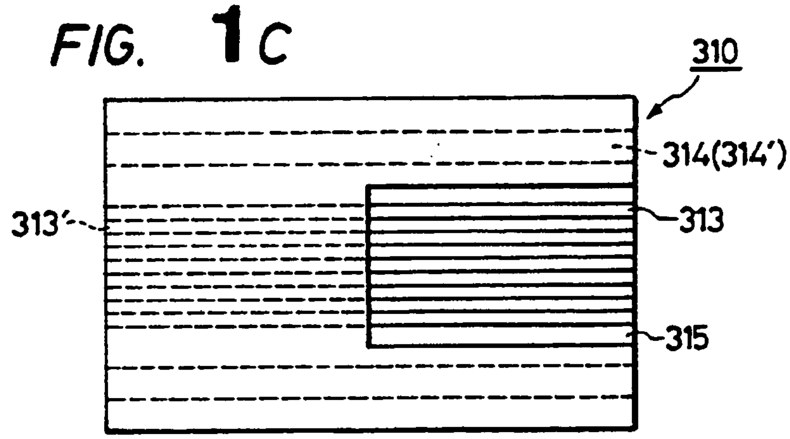

FIG. 1D

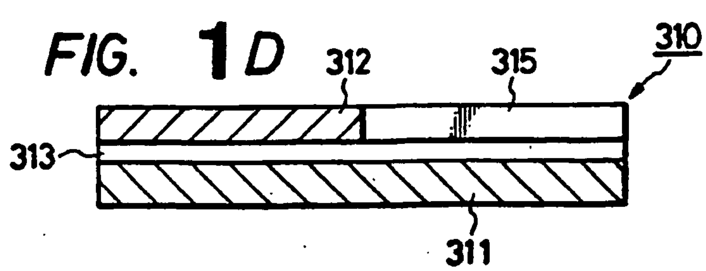

FIG. 2A

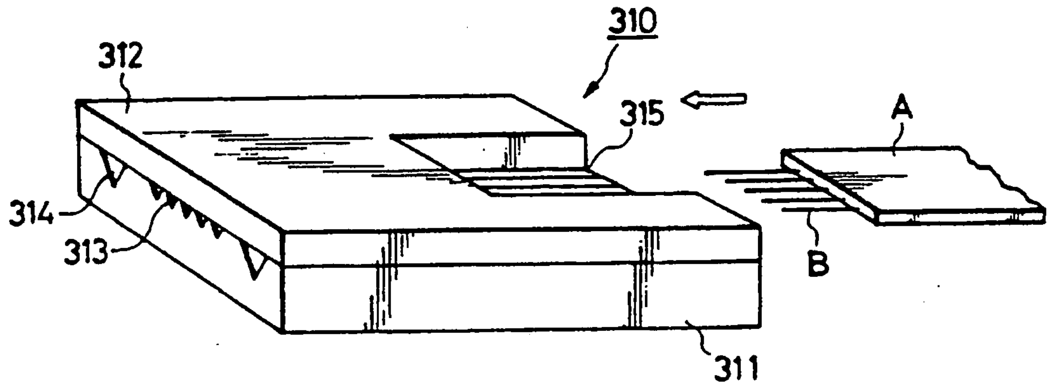

FIG. 2B

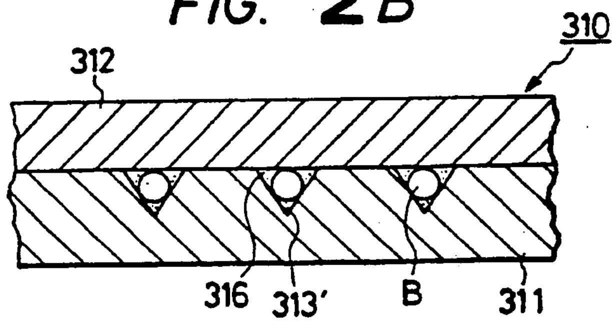

FIG. 2C

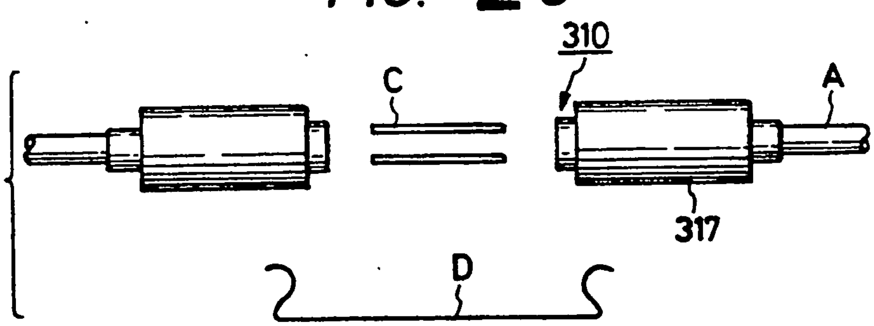

FIG. 3A

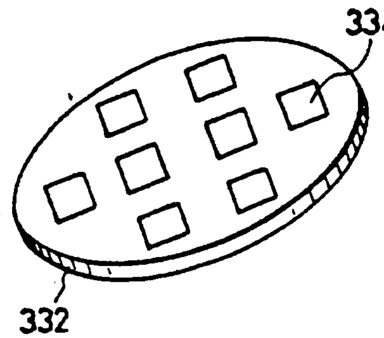

FIG. 3B

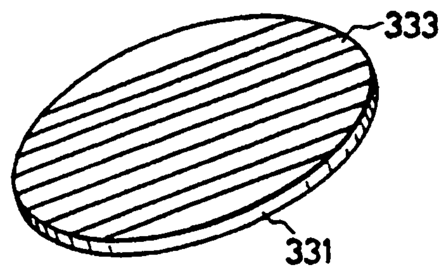

FIG. 3C

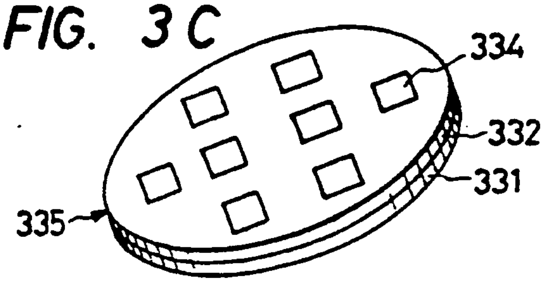

FIG. 3D

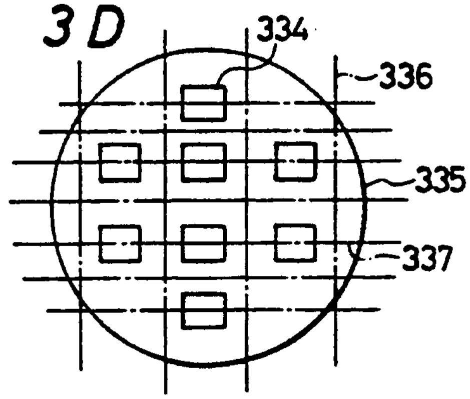

FIG. 3E

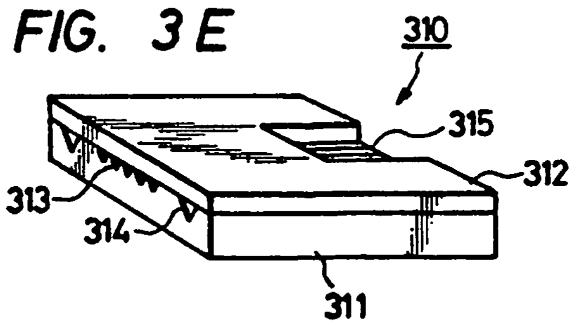

FIG. 3F

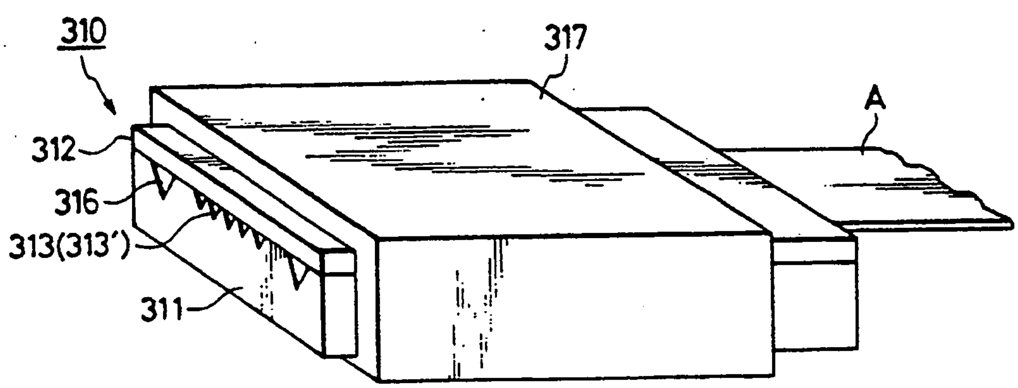

FIG. 4A

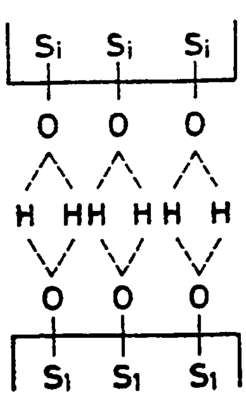

FIG. 4B

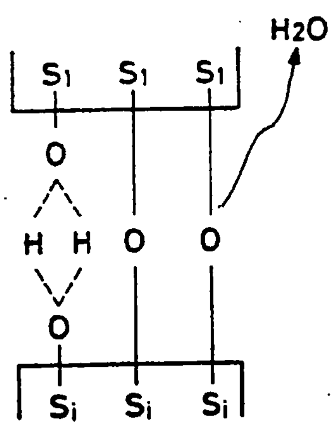

FIG. 4C

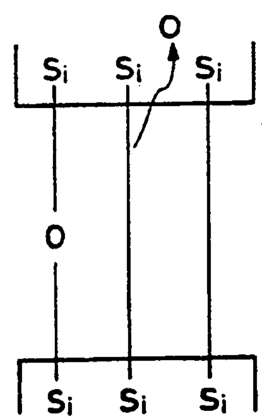

FIG. 5

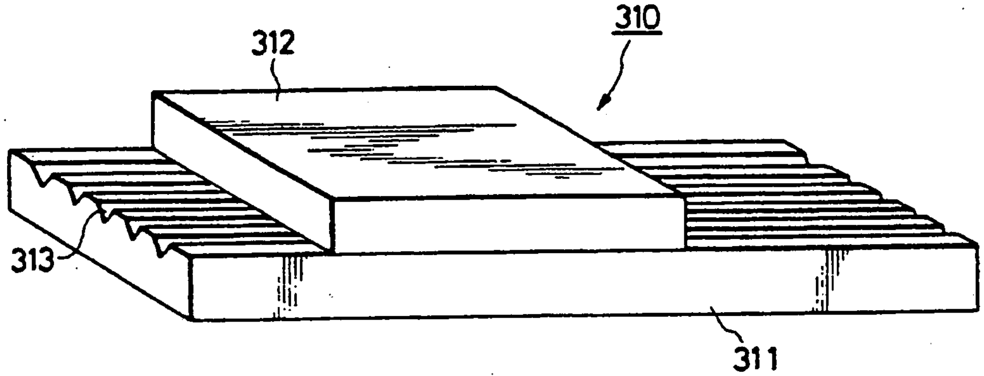

FIG. 6

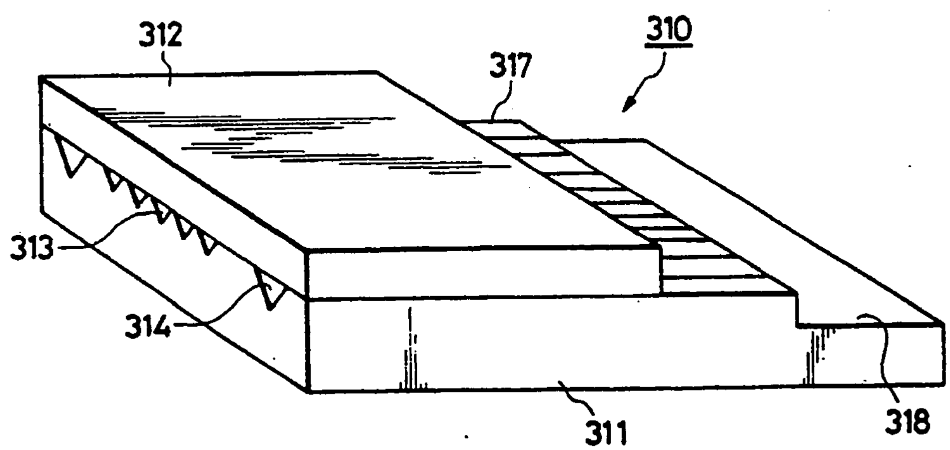

FIG. 7A

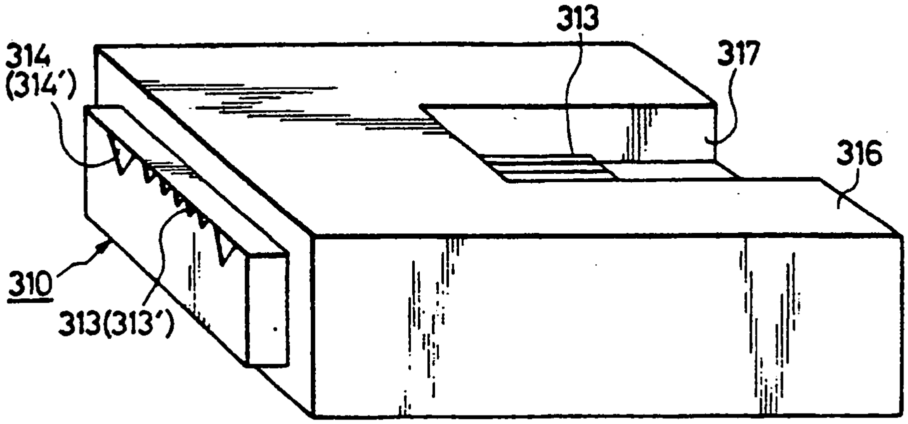

FIG. 7B

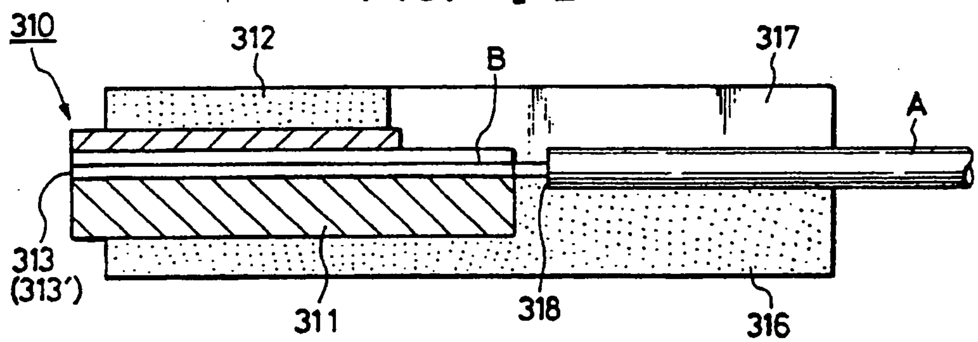

FIG. 8

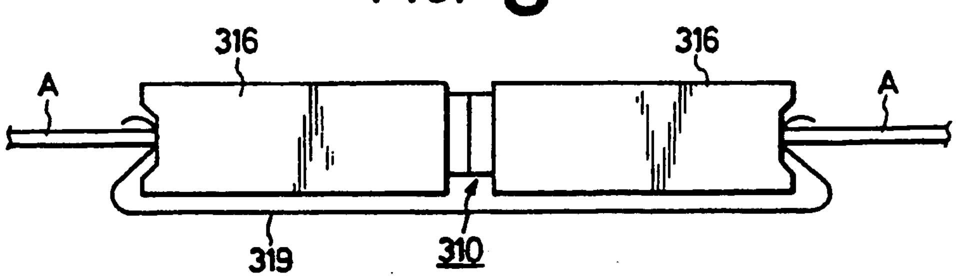

FIG. 9